

be approximated by two straight lines, the light elements lying on a steeper line through the origin, while the heavy elements lie on a less steep line with a positive intercept. Increasing  $k_1$  has the opposite effect. A variation in  $k_1$  of  $\pm 0.2 \times 10^{12}$  cm<sup>-1</sup>, or in  $V$  of  $\pm 2$  Mev, begins to produce appreciable bending. A reduction in  $K$ , with fixed  $k_1$ , introduces a curvature in the radius line, the center being pulled down and the two ends raised. The curvature becomes noticeable if  $K$  is reduced to less than  $K = 1.9 \times 10^{12}$  cm<sup>-1</sup>, however  $K$  can be almost doubled before the opposite curvature becomes very pronounced. For example,  $K = 3.0 \times 10^{12}$  cm<sup>-1</sup> gives an about equally good straight line,  $R = 1.39A^{1/3} \times 10^{-13}$  cm. The total cross-section measurements thus determine the potential fairly well, but are quite insensitive to the absorption coefficient. Measurements of  $\sigma_a$  and of the differential diffraction scattering are required for a better evaluation of  $K$ . It should be noted that while  $k_1$  and  $K$  are determined directly from the cross sections, the evaluation of  $V$  depends also on the energy of the incident neutrons. Cook *et al.* state that the energy of the neutrons detected in their experiment may be a little lower than 90 Mev, lying somewhere

between 80 and 90 Mev. If we took  $E = 80$  Mev, we would find  $V = 28.8$  Mev.

For  $K = 2.2 \times 10^{12}$  cm<sup>-1</sup>, the values of  $KR$  range from 0.58 for Li to 1.87 for U. It will be seen from Fig. 1 that the nuclear opacity,  $\sigma_a/\pi R^2$ , would vary from 0.52 for Li to 0.88 for U. It will also be seen that over this range of values of  $KR$  it would be expected that  $\sigma_a$  will be nearly twice as large as  $\sigma_n$ .

If one plots the angular distribution of the diffraction scattering given by (9) (i.e.,  $d\sigma_a(\theta)/d\sigma_a(0)$  versus  $kR \sin\theta$ ) one finds curves for the heaviest nuclei which are indistinguishable from that for an opaque nucleus (Eq. (4)), at least as far as the first minimum of the diffraction pattern. For the lighter nuclei, the form of the curve is closely the same, but with an altered scale of abscissa, corresponding to using an effective radius somewhat smaller than the true radius. The increase in the half width of the diffraction peak is zero for  $KR = 1.78$  (Pb), 3.7 percent for  $KR = 1.20$  (Cu), 6.2 percent for  $KR = 0.90$  (Al) and 9.6 percent for  $KR = 0.63$  (Be). Measurements of the diffraction scattering and of the absorption are now in progress in this laboratory.

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### He<sup>3</sup> Isotopic Abundance\*

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The isotopic abundance of He<sup>3</sup> in one sample each of "well" helium and "atmospheric" helium has been measured by detecting the He<sup>3</sup>( $n,p$ )H<sup>3</sup> disintegrations induced by thermal neutrons. The helium gas was put into a proportional counter, the disintegration rate compared to that with nitrogen in the counter, and the He<sup>3</sup> content deduced from the known ratio of the He<sup>3</sup> and N disintegration cross sections.

#### INTRODUCTION

PREVIOUS measurements<sup>1,2</sup> have indicated that He<sup>3</sup> is present in natural helium in amounts of the order of one part in  $10^6$  to  $10^7$ , and that the abundance varies by more than a factor of 10 depending on the source of the helium. He<sup>3</sup> concentration determination is of special current interest in connection with nuclear investigations of interactions between elementary nuclei, and in connection with investigations of the thermodynamic behavior of He<sup>3</sup> and He<sup>4</sup> at temperatures of liquid helium.

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<sup>1</sup> L. T. Aldrich and A. O. Nier, Phys. Rev. **70**, 983 (1946); **74**, 1225 (1948); **74**, 1590 (1948).

<sup>2</sup> L. W. Alvarez and R. Cornog, Phys. Rev. **56**, 613 (1939); **56**, 379 (1939).

In the present work measurements were made of the isotopic abundance of He<sup>3</sup> in two samples of natural helium: one from wells near Amarillo, Texas, and one from air reduction processing. The presence of He<sup>3</sup> was detected by counting ionization pulses arising from the disintegration products of the reaction He<sup>3</sup>( $n,p$ )H<sup>3</sup> induced by thermal neutrons. The cross section for this reaction is about 5000 barns,<sup>3</sup> which is sufficiently large to make it possible to detect the He<sup>3</sup> in natural helium samples. Data were also taken with nitrogen in the counter, in which case one detects the N<sup>14</sup>( $n,p$ )C<sup>14</sup> disintegrations. Since the protons from the He<sup>3</sup> and N reactions have very closely the same range, the "wall effect" corrections will be similar for the two cases. If counting is done on nitrogen and on

<sup>3</sup> J. H. Coon and R. A. Nobles, Phys. Rev. **75**, 1358 (1949).

TABLE I. Determination of disintegration rates.

	Partial press. $p$ of gas in atmos.	Press. of added argon in atmos.	Counter voltage	Approx. total number dis- integrations counted	Additive correction $\Sigma w$	Corrected counts per min. = $D$
N <sub>2</sub> —run 1	0.258	1.71	3725	12,000	137.0	1314 } Av. = 1278 1243 }
run 2	0.258	1.71	3725	12,000	111.0	
"Well" helium	7.47	0.27	2010	7000	0.32	9.15
"Atmospheric" helium	1.143	0.65	1485	9000	0.54	10.55
Pure argon	1.95	--	2670	—	—	—

helium with the same neutron flux, then the disintegration rates  $D$  taking place within the sensitive volume of the counter will be related by:

$$D_N/D_{He} = (\sigma_N n_N / \sigma_{He^3} n_{He^3}), \quad (1)$$

where  $\sigma$  is the disintegration cross section and  $n$  the number of atoms per cm<sup>3</sup>. If  $I$  is the relative concentration of He<sup>3</sup> in the helium and  $p$  is pressure, then the above ratio may be written

$$D_N/D_{He} = (\sigma_N / \sigma_{He^3}) \cdot (2p_N / Ip_{He}). \quad (2)$$

Using the ratio  $\sigma_N / \sigma_{He^3}$  elsewhere reported,<sup>3</sup> we can

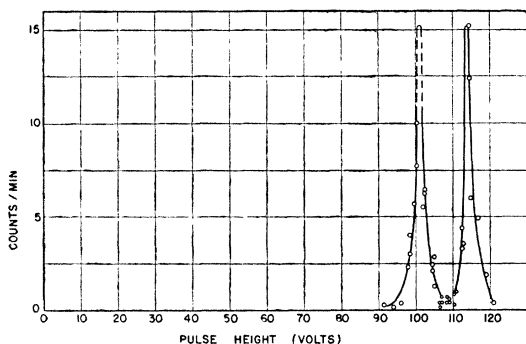


FIG. 1. Differential pulse height distribution curve obtained with a thin deposit of normal uranium mounted on the inner wall of the counter. The two peaks correspond to the alpha-particle groups from U<sup>234</sup> and U<sup>238</sup>. 3.0 atmos. argon pressure.

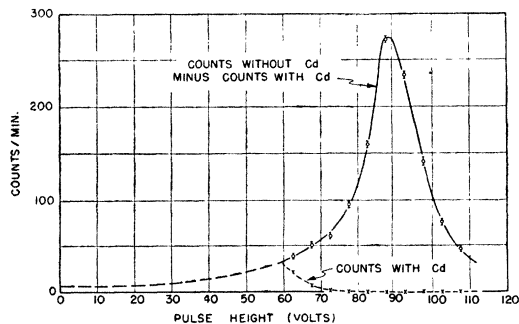


FIG. 2. Pulse height distribution curves obtained by counting N<sup>14</sup>( $n, p$ )C<sup>14</sup> disintegrations. The plotted points represent the number of pulses in a 5-volt pulse height interval and the point is plotted at the center of the interval. The vertical lines indicate standard deviations computed by taking the square root of the total number of counts obtained and adjusting this to the counting rate.

TABLE II. He<sup>3</sup>/He<sup>4</sup> Ratio  $\times 10^{-7}$ .

	Present measurement	Aldrich and Nier
"Well" helium (Amarillo, Texas)	1.73	1.4
"Atmospheric" helium (Airco)	13.0	12.0
Beryl crystals (Amarillo, Texas)		0.6, 1.4, 1.4, 2.0
Radioactive ores		<0.3

therefore obtain  $I$  by determining the counting rates at measured pressures.

#### APPARATUS AND PROCEDURES

The techniques and apparatus used were essentially the same as those reported in the article by Coon and Nobles in this issue of the Physical Review. There were a few exceptions as follows. A normal uranium alpha-particle emitter was used inside the counter instead of plutonium. A calcium purifier was attached directly to the counter in the manner reported by Klema and Barschall.<sup>4</sup> This purifier was desirable since the effect of a small N<sub>2</sub> impurity in the helium would not be distinguishable from the effect of He<sup>3</sup>. The counter gas flowed continually over calcium turnings in the purifier at about 300°C. The effectiveness in removing nitrogen was tested by contaminating a pure argon filled counter with a small amount of air, and observing the drop in neutron induced counting rate as the calcium removed the nitrogen.

#### RESULTS

The pulse height distribution curves are shown in Figs. 1 to 4. The curves show counting data taken both with and without a cadmium cover over the counter. The count with cadmium is subtracted as a background except in the small pulse region where gamma-rays are detected, and where neutron capture gammas from the cadmium interfere. From Fig. 2 it is seen that in the case of nitrogen the count with cadmium is a very small fraction of the count without cadmium (about one part in 800)

<sup>4</sup>E. D. Klema and H. H. Barschall, Phys. Rev. **63**, 18 (1943).

except in the region of small pulses. In the case of helium (see Figs. 3 and 4) the count without cadmium is relatively high because of the presence of a few residual high energy neutrons getting to the region of the counter in spite of the large amount of graphite between the counter and the fast neutron source. The He<sup>4</sup> recoils from these fast neutrons are appreciable in number because of the tremendous abundance of He<sup>4</sup> as compared to He<sup>3</sup>. Figure 3 also shows the cadmium difference curve obtained with 1.95-atmosphere pure argon in the counter. This count with argon serves as a background to be subtracted from the cadmium difference curves gotten with helium.

The number of disintegrations  $D$  taking place within the sensitive volume of the counter was obtained from

$$D = \sum C_1 - \sum C_2 - \sum A + \sum w,$$

where  $\sum C_1$  is the counting rate without cadmium summed over all channels counted;  $\sum C_2$  is the counting rate with cadmium summed over all channels counted;  $A$  is the background as determined with pure argon, this also being a cadmium difference count; and  $\sum w$  is the "wall effect" correction determined by adding up the number of pulses under the extrapolated lower end of the corrected pulse height distribution curves. The correction  $\sum w$  accounts at least in part for all small pulses whether they are due to "wall effect" or to other causes which reduce their size so much that they cannot be counted in the lowest pulse height counting channel.

Inserting values for  $p$  and  $D$  from Table I into relation (2), using  $\sigma_{\text{He}^3}/\sigma_N = 2860$ , and solving for  $I$  gives values listed in Table II, along with values obtained by Aldrich and Nier.<sup>1</sup> Differences between the two sets of values are probably not significant, especially in view of the variations which Aldrich and Nier find in the He<sup>3</sup> abundance for samples of different origin.

For correlating the He<sup>3</sup> abundance with the source of helium, the mass spectrograph is better than the present counter technique because of the large quantity of gas necessary in the counter method. For analysis of the He<sup>3</sup> content in enriched samples the counter technique may offer some advantages in ease and accuracy, depending of course on available facilities.

The accuracy of the present measurement is estimated at  $\pm 15$  percent, which does not include the error in the value of  $\sigma_{\text{He}^3}/\sigma_N$  which is about  $\pm 5$  percent. Of the 15 percent error, approximately 6

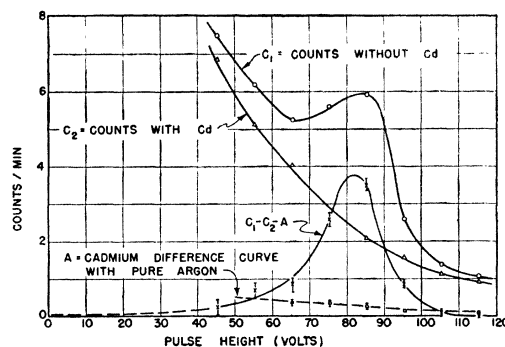


FIG. 3. Pulse height distribution curves obtained with "well" helium. The plotted points represent the number of pulses in a 10-volt pulse height interval and the point is plotted at the center of the interval. The difference curve,  $C_1 - C_2 - A$ , corresponds to the number of He<sup>3</sup>( $n, p$ )H<sup>3</sup> disintegrations.

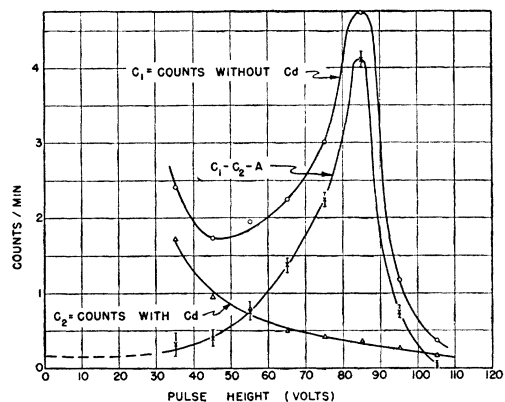


FIG. 4. Pulse height distribution curves obtained with "atmospheric" helium. The plotted points represent the number of pulses in a 10-volt pulse height interval and the point is plotted at the center of the interval. The difference curve,  $C_1 - C_2 - A$ , corresponds to the number of He<sup>3</sup>( $n, p$ )H<sup>3</sup> disintegrations.

percent is statistical error determined by considering the number of counts obtained. The correction  $\sum w$  which involves extrapolation of the curve to zero pulse height may introduce 5 percent error. Background fluctuations from spurious electrical disturbances assume more importance because of the low counting rates. There is an undetermined effect of capture gammas from neutron capture in cadmium; these gammas cause a larger number of small pulses when cadmium surrounds the counter than when it does not.

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